ISSN 1063-7737, Astronomy Letters, 2009, Vol. 35, No. 1, pp. 33–38. © Pleiades Publishing, Inc., 2009.
Original Russian Text © M.G. Revnivtsev, A.Yu. Kniazev, S.Yu. Sazonov, R.A. Burenin, A. Tekola, D.A.H. Buckley, M.L. Pretorius, J. Menzies, W. Lawson, 2009, published in Pis'ma v Astronomicheskiĭ Zhurnal, 2009, Vol. 35, No. 1, pp. 37–43.

Optical Identification of the Source IGR J08390–4833 from the INTEGRAL All-Sky Survey

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Received July 17, 2008

Abstract—Results of the optical identification of the hard X-ray source IGR J08390–4833 recently discovered in the INTEGRAL all-sky survey are presented. We show that the source is most likely a cataclysmic variable, i.e., an accreting white dwarf in a binary. Analysis of its optical light curve clearly reveals intrinsic variability on timescales of the order of an hour or longer. However, the short time of the source's optical observations does not allow a definitive conclusion about the periodicity of the detected variability to be reached. Further optical and X-ray observations are required for a more accurate classification of the source.

PACS numbers : 97.30.Qt; 97.80.Gm; 98.62.Tc; 98.70.Qy

DOI: 10.1134/S1063773709010046

Key words: *X-ray sources, optical identifications*.

INTRODUCTION

As a rule, X-ray sky surveys allow catalogs of objects of various types to be compiled with minimum selection effects. In turn, these catalogs allow the properties of the populations of various objects to be studied. However, for the parameters of the populations of astrophysical objects to be estimated most accurately, all cataloged sources must be identified and classified.

The INTEGRAL observatory (Winkler et al. 2003) is currently conducting one of the most sensitive hard X-ray all-sky survey (Krivonos et al. 2007). As a result, the parameters of the populations of active galactic nuclei in the local Universe (Sazonov et al. 2007), X-ray binaries (Lutovinov et al. 2005; Bodaghee et al., 2007; Revnivtsev et al. 2008a), and cataclysmic variables (Revnivtsev et al. 2008b) have already been estimated.

The INTEGRAL all-sky catalog contains more than 400 sources; the nature of a substantial fraction of them is not yet known. Our group systematically carries out optical observations of unidentified sources from the INTEGRAL all-sky survey to determine their nature (Bikmaev et al. 2006a, 2006b, 2008; Burenin et al. 2006a, 2006b, 2008; Mescheryakov et al. 2006). Increasing the completeness of the INTEGRAL all-sky catalog raises significantly its scientific value.

In this paper, we present the results of our identification of the hard X-ray source IGR J08390–4833.

OBSERVATIONS AND DATA ANALYSIS

The source IGR J08390–4833 was discovered through INTEGRAL observations (Sazonov et al. 2008). Further Chandra observations (Sazonov et al. 2008) allowed the X-ray source to be confidently associated with an optical object with an apparent magnitude $V \sim 16^m$ at the position with RA = $08^h38^m49.11^s$ and Dec = $-48°31'24''.7$. An image of a 1.4×1.2-arcmin field around the source from the DSS2-R sky survey is shown in Fig. 1.

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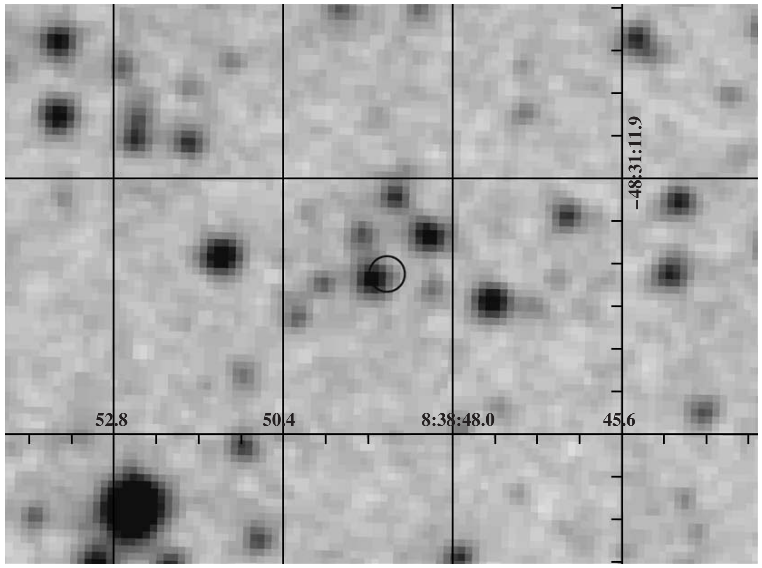


Fig. 1. Image of a 1.4 × 1.2-arcmin field around IGR J08390−4833 from the DSS2-R survey. The circle indicates the position of the X-ray source from Chandra observations. The radius of the circle shows the positional uncertainty of the X-ray source.

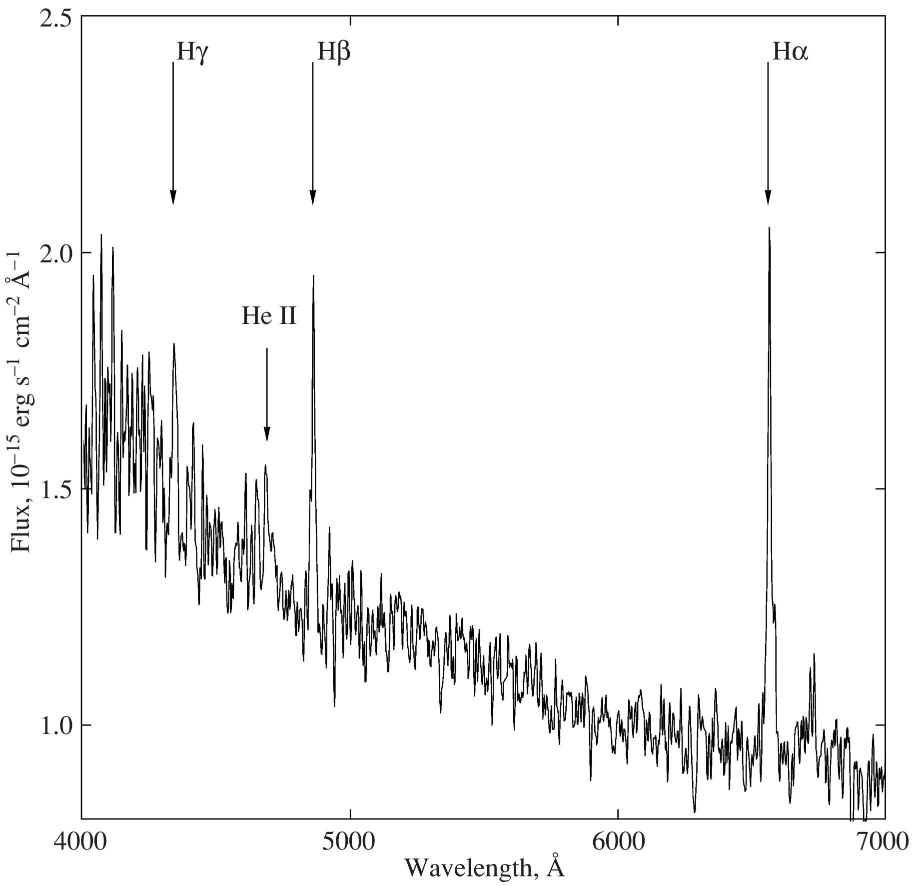


Fig. 2. Optical spectrum of IGR J08390−4833 averaged over all observations.

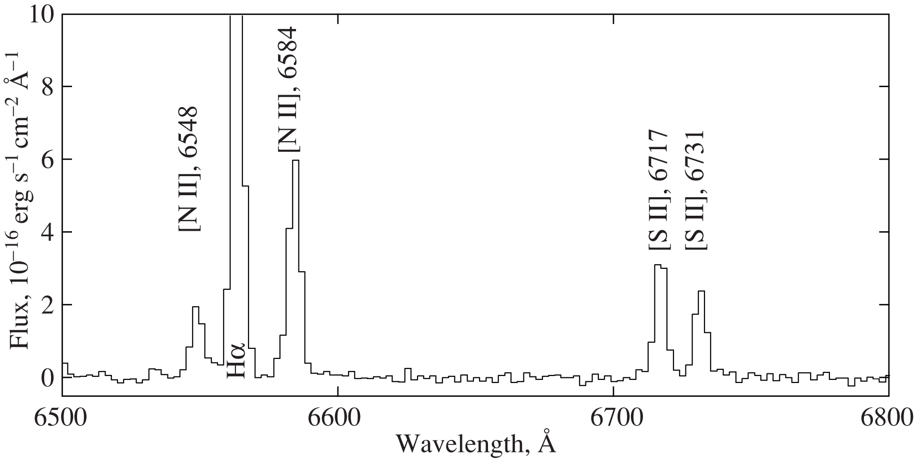


Fig. 3. Part of the spectrum for the nebula detected around IGR J08390−4833.

Spectra

Spectroscopic observations of IGR J08390−4833 were carried out with the 1.9-m telescope of the South-African Astronomical Observatory (SAAO) during several nights in April 2008. A long-slit ($3' \times 1.5''$) Cassegrain spectrometer with a 300 lines mm^{-1} diffraction grating and a 266×1798-pixel CCD array was used in the observations. This made it possible to cover the spectral range ∼3500−7300 Å with a resolution of ∼7 Å (FWHM). The seeing varied within the range 1.″0−1.″6 during the observations, but it remained stable during each individual night. Cu−Ar arc emission was used for wavelength calibration. The airmasses during the observations were 1.04−1.18. Spectrophotometric standards were observed to calibrate the absolute fluxes.

The data were processed using the standard IRAF software package.[1] The cosmic-ray tracks were removed using the MIDAS software package. The expected absolute accuracy of the wavelengths in our observations is ∼0.4 Å. The night-sky spectrum was subtracted after the calibration of the spectra.

Since emission lines typical of tenuous nebulae were detected around the source (see below), we obtained Hα images of this region with the 1-m SAAO telescope to determine the relationship of this nebula to the hard X-ray source. One pair of V and Hα images (300-s exposure time) was obtained on May 3, 2008, and four pairs of R and Hα images (1200-s exposure time) were obtained on May 10, 2008.

Photometry

To study the temporal variability of the flux from IGR J08390−4833, we obtained its optical light curve with the 1-m SAAO telescope on April 26, 2008.

Fast photometric observations were carried out with the CCD photometer of the University of Cape Town (UCT CCD, O'Donoghue 1995) in white light (without filters). The length of a single time interval in these observations was 10 s. The UCT CCD observations without filters roughly correspond to

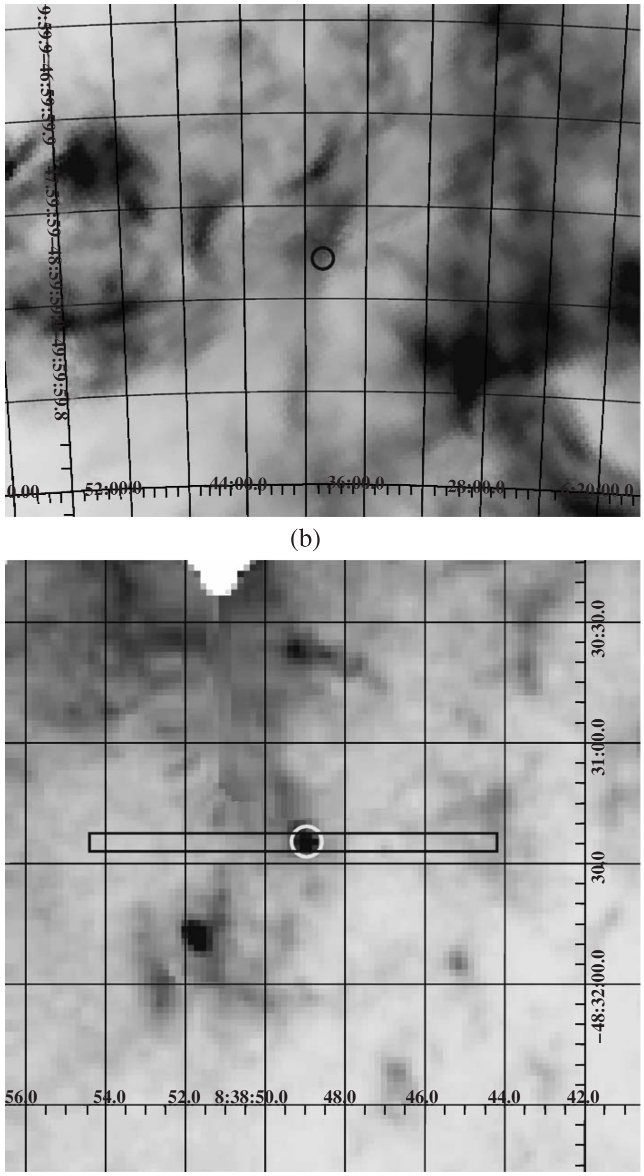
Ratios of the emission-line fluxes in the spectrum of the nebula around IGR J08390−4833 (the ratios of the measured, F, and dereddened, I, fluxes)

λ_0(Å) Species	$F(\lambda)/F(\mathrm{H}\beta)$	$I(\lambda)/I(\mathrm{H}\beta)$
3727 [O II]	3.69 ± 0.29	3.90 ± 0.32
4101 Hδ	0.29 ± 0.07	0.30 ± 0.10
4340 Hγ	0.48 ± 0.07	0.50 ± 0.08
4861 Hβ	1.00 ± 0.08	1.00 ± 0.09
4959 [O III]	0.17 ± 0.06	0.17 ± 0.06
5007 [O III]	0.45 ± 0.05	0.45 ± 0.05
5869 He II	0.09 ± 0.04	0.09 ± 0.04
6548 [N II]	0.50 ± 0.05	0.47 ± 0.04
6563 Hα	3.13 ± 0.21	2.94 ± 0.22
6584 [N II]	1.47 ± 0.10	1.39 ± 0.10
6717 [S II]	0.83 ± 0.06	0.78 ± 0.06
6731 [S II]	0.59 ± 0.04	0.55 ± 0.04
EW(Hβ), Å	131*	
C(Hβ), dex	0.08	
A_B, ^{m}	0.23	
S II $\lambda6731/\lambda6717$	1.409 ± 0.156	
N_e(S II $\lambda6731/\lambda6717$), cm^{-3}	20^{+135}_{-10}	

Note. EW(Hβ) is the equivalent width of the Hβ line, C(Hβ) is the reddening coefficient, A_B is the interstellar extinction in the B band, and N_e is the density of the emitting plasma.
*Since the continuum in the nebula spectrum is weak, the emission-line equivalent width is difficult to determine. However, we expect the uncertainty in the equivalent width to be no larger than 30%.

[1] http://iraf.noao.edu/

(a)



(b)

Fig. 4. (a) Image of a $7^{\circ}.5 \times 6^{\circ}.1$ field around IGR J08390-4833 in a narrow (effective width ∼17 Å) $H\alpha$ filter (obtained using the Skyview service of the HEASARC archive; the image is based on the results by Finkbeiner (2003)). The circle marks the position of IGR J08390−4833. (b) Image of a smaller ($2.6' \times 2.4'$) field around IGR J08390−4833 in an $H\alpha$ filter obtained with the 1-m SAAO telescope. The unsubtracted stars and other defects were removed from the image. The bright star in the Hα image is IGR J08390−4833 (marked by the circle). The rectangle shows the size and position of the spectrograph slit used to take the spectra of the source and the nebula.

the wavelengths of the Johnson V filter, but with a much broader passband. The absence of filters in the observations makes an accurate absolute calibration of the observed fluxes from the source impossible. Therefore, the accuracy of the absolute value of the object's apparent magnitude is not better than $\sim 0^{m}_{\cdot}1$. The light curve of the optical source was obtained by the method of differential photometry.

RESULTS

Spectra

The spectrum of IGR J08390−4833 averaged over all observations with the 1.9-m telescope is presented in Fig. 2. The intense unshifted Balmer emission lines clearly show that the source is located in our Galaxy. The shape of the optical continuum and the series of intense Balmer lines in the source spectrum clearly indicate that the source is most likely a cataclysmic

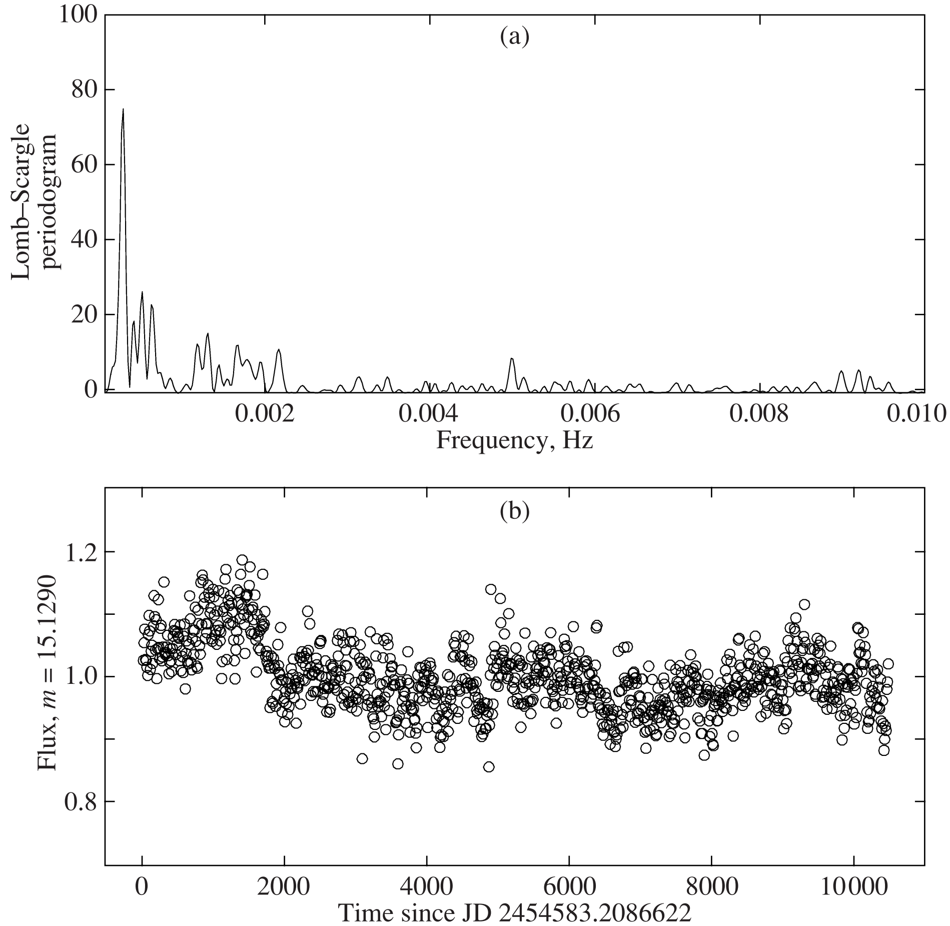


Fig. 5. (a) Lomb–Scargle periodogram of the light curve corrected for the long-term trend (see the text); (b) optical light curve of IGR J08390–4833.

variable (see, e.g., Schmidt et al. 1986; Bikmaev et al. 2006b; Masetti et al. 2007), i.e., an accreting white dwarf in a binary.

Nebular Emission Lines

The 2D spectrum of the region bounded by the long slit (shown in Fig. 4) exhibits a complex of emission lines originating in a fairly extended region around IGR J08390–4833. The intense emission lines include, in particular, O II, [N II] 6548, 6584 Å, and [S II] 6716, 6731 Å.

It is interesting to check whether there is a causal relationship between the hard X-ray source and the nebula producing these emission lines, since some of the cataclysmic variables (accreting white dwarfs) can sometimes pass through the classical nova phase, i.e., thermonuclear explosions of the accreted matter can occur on the white-dwarf surface to produce a nebula (see, e.g., Slavin et al. 1995).

For this purpose, we obtained and analyzed the nebular spectrum (see Fig. 3). The measured emission-line flux ratios are listed in the table. The fluxes of all emission lines were measured using MIDAS routines (for more detail, see Kniazev et al. 2004). The physical parameters of the emitting media were estimated using diagnostics from Kniazev et al. (2008a). The density of the emitting medium was determined by assuming that all emission lines originated in a single-temperature plasma with a uniform density.

The ratios of the line fluxes clearly show that the lines originate in a hot tenuous medium, which is most likely an extended H II region (see, e.g., the diagnostics of H II regions by Kniazev et al. (2008b)) clearly seen in the Hα image of the field around the source (Finkbeiner 2003, Fig. 4).

To study the structure of the nebula around IGR J08390–4833 on smaller angular scales, we obtained an Hα image of this region with the 1-m SAAO telescope (see Fig. 4). The image shows no clear evidence that the nebula is causally related to IGR J08390–4833.

Light Curve

An optical light curve of the source is presented in Fig. 5b. A Lomb–Scargle periodogram (Lomb 1976) of this light curve is shown in Fig. 5a. Before constructing the periodogram, we corrected the light curve of the source for the long-term trend—the quadratic best fit to the light curve was subtracted from the original light curve.

In the absence of intrinsic flux variability (i.e., in the presence of variations in the light curve only due to statistical uncertainties in the measured flux), the values of the Lomb–Scargle periodogram are distributed exponentially, i.e., the probability that the periodogram value exceeds some threshold x is $P(>x) = \exp(-x)$. We see from Fig. 5 that the light curve of the source clearly shows intrinsic variability at Fourier frequencies $f < 7 \times 10^{-4}$ Hz.

Large peaks are clearly seen in the periodogram; the highest peak corresponds to a Fourier frequency of $(2.6 \pm 0.3) \times 10^{-4}$ Hz or a period $P \sim 1.1 \pm 0.1$ h. However, since the total exposure time in these observations is short (about 3 h), we cannot definitely conclude that the detected variability is periodic in pattern. Further observations of the source with longer exposure times are needed to make a more definitive judgment.

The set of available data suggests that the source is most likely a cataclysmic variable, i.e., an accreting white dwarf in a binary. The source can be further classified into subclasses of cataclysmic variables (e.g., a dwarf nova, a polar, an intermediate polar) only after its additional optical and X-ray observations.

ACKNOWLEDGMENTS

This work was supported by the Russian Foundation for Basic Research (project nos. 07-02-01051 and 07-02-00961), program no. NSh-5579.2008.2, and the “Origin and Evolution of Stars and Galaxies” Program of the Presidium of the Russian Academy of Sciences.

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Translated by A. Serber